Erosion

Background and Objectives

The purpose of the Erosion module is to characterize the physical landscape of the watershed and assess its susceptibility to erosion from natural processes and land use practices. The primary product is a geomorphic land type map that categorizes areas based on topographic, geologic, and soil properties and identifies the erosion potential of each land type. Geomorphology is the study of landforms. It focuses on the processes that create landforms, such as rainfall and runoff, and the relation of geologic material to surface features (Dunne and Leopold 1977). Geomorphic information can be used to forecast the effects of different land use practices on the landscape.

The Level 1 procedure relies primarily on existing information about erosion in the watershed. Topography, soil, and geology maps are used to delineate land types based on physical landscape characteristics. The objective of a Level 1 assessment is to generally correlate erosion potential with various land types. Further evaluation and data collection in a Level 2 assessment are often necessary to validate land type erosion potentials.

Level 2 methods require expertise in evaluating geology, soils, and erosion processes. Erosion processes are evaluated in more detail, and the assessment typically involves field surveys. A greater effort is made to quantify sources of erosion from natural processes and land use activities.

Erosion Module Reference Table

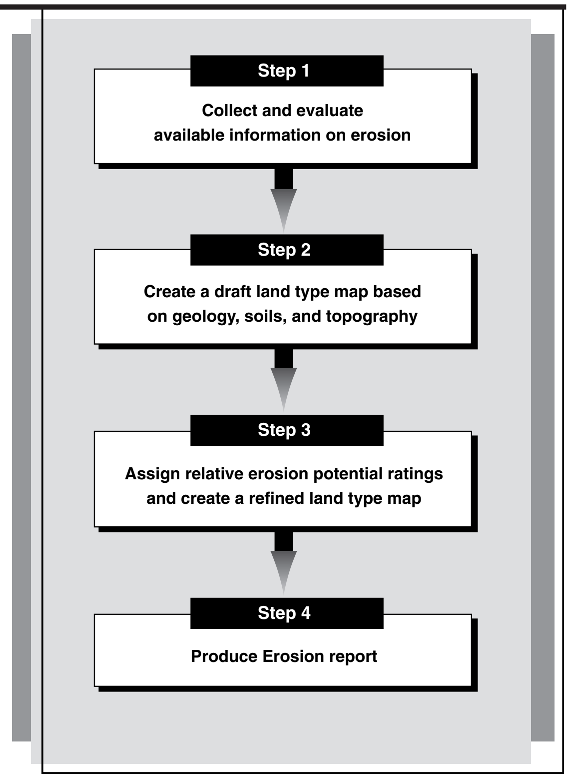
Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
E1: What and where are the dominant erosion processes in the watershed?	• Aerial photos • Soil surveys • Geology maps • Topography maps • Interviews (anecdotal information)	• Review of existing map and survey data • Erosion severity classification	• Detailed field review of erosion • Revised Universal Soil Loss Equation (RUSLE) • Water Erosion Prediction Procedure (WEPP)
E2: How do land use activities affect erosion processes?	• Aerial photos • Soil surveys • Topography maps • Interviews (anecdotal information)	• Review of existing map and survey data	• Detailed field review of erosion • RUSLE • WEPP
E3: What geomorphic land types exist in the watershed and where are they located?	• Aerial photos • Soil surveys • Geology maps • Topography maps	• Review of existing map and survey data • Land type classification	• Review of aerial photos • Field review of geomorphic land types
E4: Where and how much has soil compaction reduced the productivity of soil in the watershed?	• Soil characteristics • Road density data • Land use maps	• Estimate the amount and location of compacted areas • Review of existing soil map and survey data	• Current/historical aerial photo analysis • Field surveys to evaluate current soil compaction hazard
E5: How significant an erosion process are landslides in the watershed?	• Landslide rates • Landslide volumes • Aerial photos	• General landslide inventory	• Detailed landslide inventory • Field Surveys
E6: Is sheetwash erosion a significant source of sediment in the watershed?	• Soil characteristics • Precipitation data • Slope length and gradients • Vegetation cover • Land use maps • Interviews (anecdotal information)	• Review of existing soil map and survey data	• Field surveys to estimate annual erosion rates • RUSLE • WEPP
E7: Is erosion from roads or road management practices a significant source of sediment in the watershed?	• Road mileage • Percent stream delivery • Road characteristics • Aerial photos	• Inventory of general road characteristics • Determine frequency of stream/water crossings by roads	• Washington State Forest Road Erosion Model • USFS R1-R4 Forest Road Erosion Model • RUSLE
E8: Has natural wildfire or modern fire suppression had an influence on erosion in the watershed?	• Aerial photos • Vegetation maps		• Reconstruct fire history • Evaluate current and historical vegetation maps • Field surveys to evaluate erosion rates or fire frequency and intensity

Erosion Module Reference Table (continued)

Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
E9: Is gully erosion an important source of sediment in the watershed, and have erosion rates changed over time?	• Aerial photos • Anecdotal information • Soil maps and survey data	• Review of existing soil map and survey data	• Current and historical aerial photo analysis of gullies • Field surveys to estimate current annual erosion rate
E10: How significant a sediment source is streambank erosion in the watershed, and how have erosion rates changed over time?	• Aerial photos • Existing stream survey data • Anecdotal information		• Current and historical aerial photo analysis of bank erosion • Field surveys to evaluate current bank erosion rates
E11: Do other significant erosion processes occur in the watershed that have not been accounted for by other evaluations?	• Topography maps • Soil maps		• Wind erosion model • Field surveys to evaluate extent of dry ravel and soil creep
E12: What are the primary sources of sediment delivery to streams, lakes, wetlands, or other waterbodies in the watershed?	• Soil maps and survey data • Topography maps • Aerial photos		• Sediment budget • RUSLE • Soil creep estimation

Level 1 Assessment

Step Chart



Data Requirements

- Topographic maps
- Geology maps
- Soil maps
- Geomorphology or land type maps (if available)
- Slope class map (as necessary)
- Aerial photos (as necessary)

Products

- Form E1. Summary of erosion observations
- Form E2. Summary of land type characteristics
- Map E1. Land types
- Erosion report

Procedure

The focus of the Level 1 assessment is to evaluate the erosion potential of land types that occur in the watershed. Land types are areas with generally uniform characteristics and physical features (e.g., topography, soils) produced by natural processes. Even if erosion is not an issue in the watershed, determining land types may be a helpful exercise to understand other ecological characteristics such as vegetation communities or water quality. Consult with other module analysts early in the assessment to determine the level of detail and the scale of land type mapping that would be most helpful.

Step 1. Collect and evaluate available information on erosion

Collect anecdotal information

Consult people who are knowledgeable about soils, geology, or erosion processes and are familiar with the watershed to help identify the type and location of erosion problems. State natural resource departments or local agricultural offices often have experts familiar with local erosion problems. The NRCS, USFS, BLM, and USGS offices may also have resources available to evaluate erosion within the watershed. Another source of experts is a university or local college, where professors might have a great deal of knowledge about local erosion issues. Finally, local land managers may be knowledgeable about erosion in the watershed over time and the type of land use activities that have caused problems. Figure 1 summarizes the potential effects of land use activities on erosion processes and community resources.

Collect topography, geology, and soil maps

Topography, geology, and soil maps are important resources for evaluating the erosion potential in the watershed. USGS 7.5-minute topography maps are typically the most useful scale for evaluating erosion at a watershed scale. Topography maps can be used to identify steep slopes as well as slope shapes (e.g., concave, undulating, planar) with higher erosion potential. They can usually be obtained locally at map or outdoor recreation stores, or they can be ordered directly from the USGS.

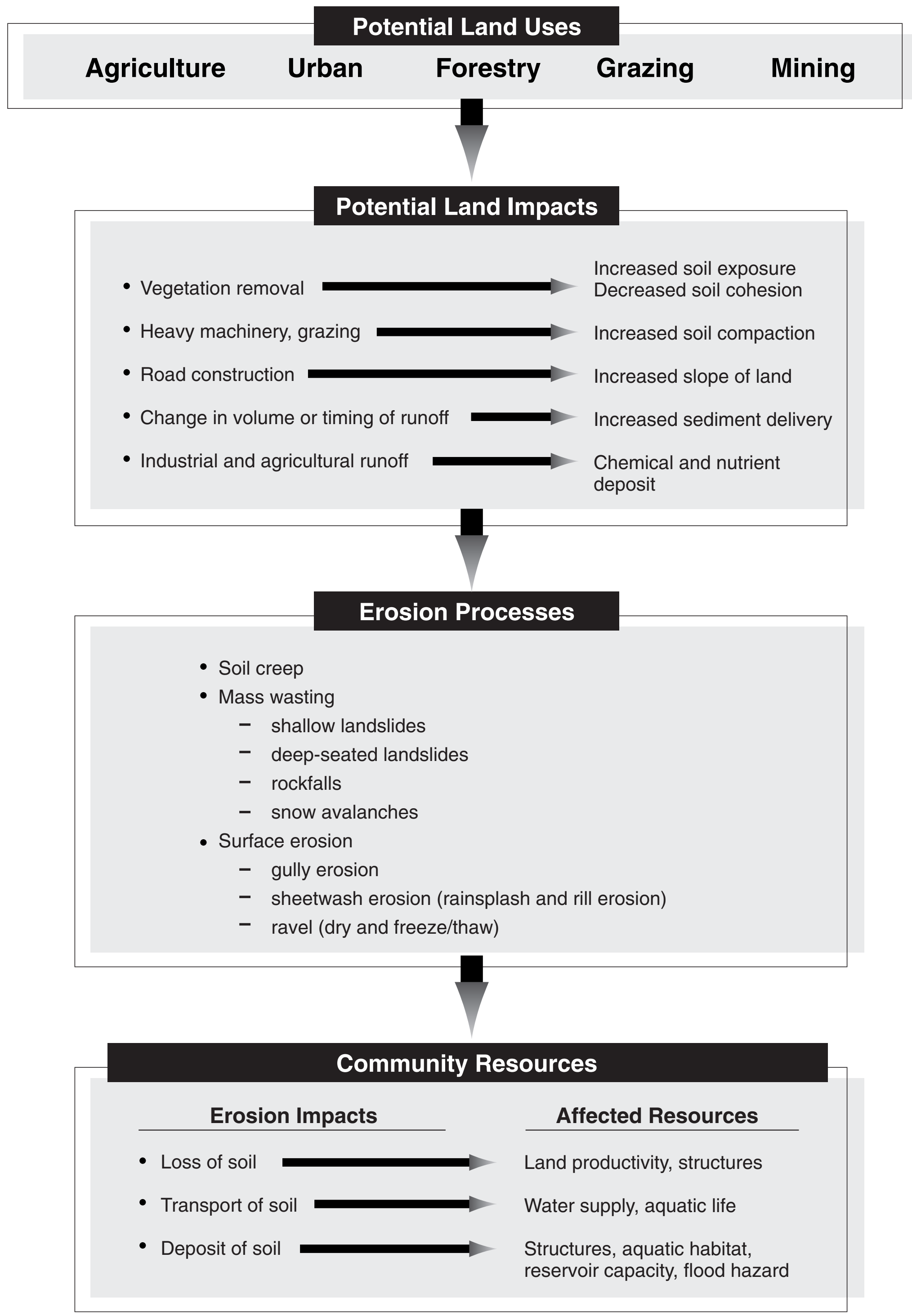
Geology and soil maps are often useful tools for evaluating baseline watershed conditions. Coordinate with the Channel, Vegetation, and Water Quality analysts to determine the type and scale of geology or soil information that would be most useful for evaluating differences in watershed conditions. USGS and state geology maps can provide helpful information on both bedrock and surficial geology. Some geologic formations may be naturally prone to erosion or be sensitive to land disturbance. These maps can be found at most university libraries, state geology departments, and USGS offices. Soil maps can provide important information about soil properties and may correlate well with specific land types. These maps can be found at most university libraries, state soil or agricultural offices, and NRCS offices. Both geology and soil maps are available as GIS overlays in many states.

Channel
Vegetation
Water Quality

Evaluate erosion information

Using information on topography, geology, and soils and anecdotal information on erosion problems, determine whether landslides, streambank slumping, and surface erosion are

Figure 1. Potential linkages between land use practices, erosion processes, and community resources



potentially active in the watershed and where they are potentially active. Aerial photos may be helpful in identifying larger areas with active erosion. If road erosion is a potential concern in the watershed, it may be helpful to gather information on road network characteristics, such as maintenance level, road density, and the frequency of stream/water crossings. Consult with the Aquatic Life and Channel analysts to determine the need for evaluating streambank erosion and the assessment detail. Form E1 (Figure 2) or a map that depicts similar information may be useful for summarizing observations and noting particular geologic formations or soil types that may be prone to erosion naturally or from management practices in the watershed.

Aquatic Life
Channel

Figure 2. Sample Form E1. Summary of erosion observations

Number	Erosion Feature	Location	Observations
1	Raw banks	Lower Silk Creek	Aerial photos and observations by tribal monitoring crew indicate unstable banks.
2	Sheetwash erosion	Road cuts on 60% slopes in the sandstone geology of Cispus River	Field investigation and county engineering reports indicate erosion problems on road cuts.
3	Gully erosion	Throughout the watershed on slopes > 30%	Aerial photos, field observation, and anecdotal information show gully erosion in the headwaters of most streams and below road drainage pipes.

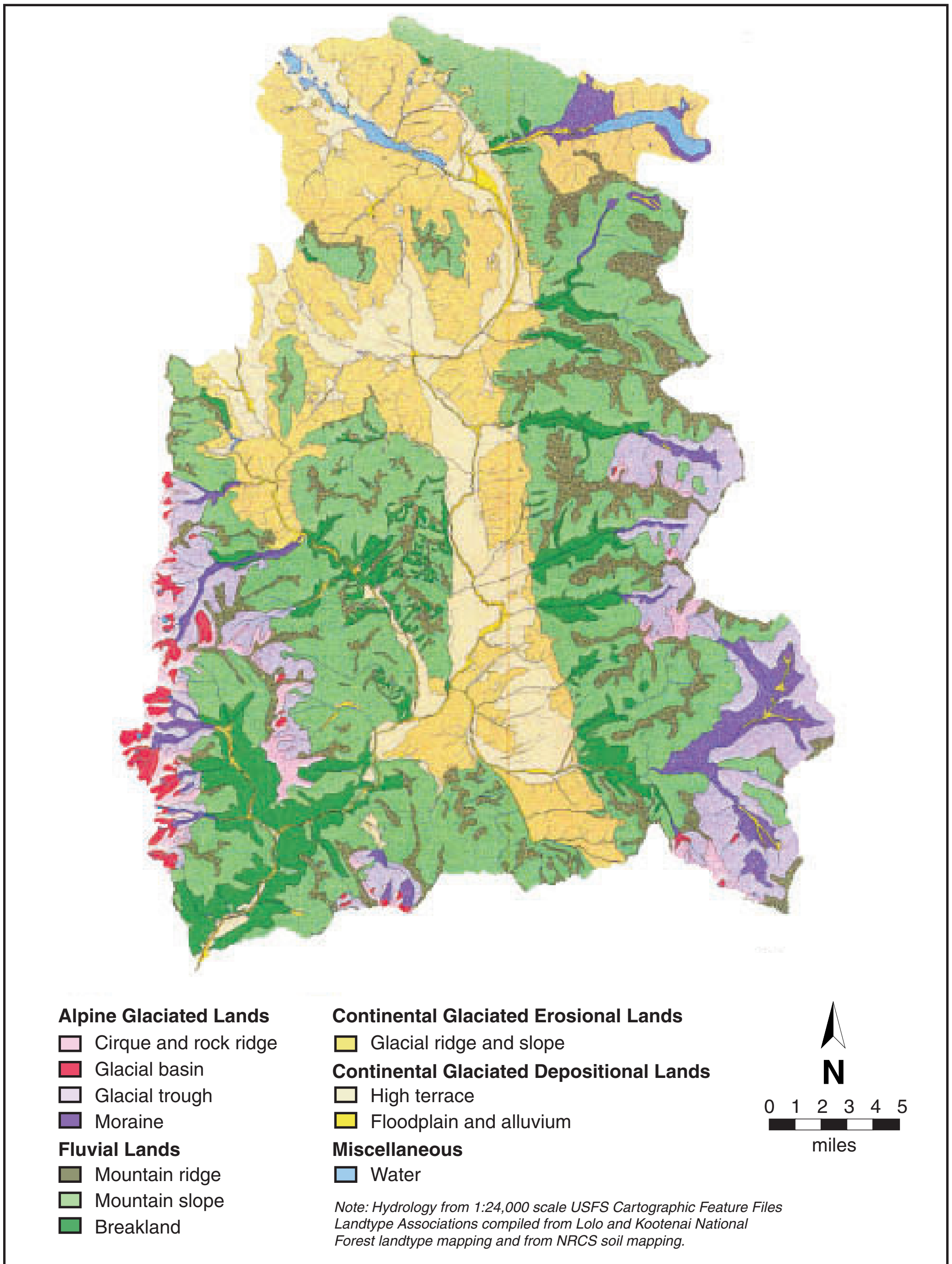
Step 2. Create a draft land type map based on geology, soils, and topography

Land types typically represent a feature with generally uniform shape and soil characteristics (Box 1). Land types should encompass the area created by a single geomorphic process (e.g., fluvial, glacial, colluvial, marine) with a set of characteristic features (Figure 3). For example, fluvial processes can create land types such as floodplain terraces, alluvial fans, and playas. Box 2 provides a list of commonly described geomorphic land types from across the United States. These land types are provided only as

Box 1. Penobscot Nation evaluation of land types

A geomorphic evaluation of the Penobscot River basin by the Penobscot Nation in Maine highlighted eskers as a land type with potentially important influence on Atlantic salmon habitat. Eskers are glacial outwash deposits from streams that flowed beneath the continental ice sheet and form narrow bands that generally parallel the Penobscot River. Where eskers cross the Penobscot River or its tributaries, gravel appears to be more prevalent and provides potentially important spawning habitat for salmon. Eskers may also be an important source of groundwater to streams to maintain cool water temperatures.

Figure 3. Landforms in the Thompson River basin, Montana



Note: Hydrology from 1:24,000 scale USFS Cartographic Feature Files Landtype Associations compiled from Lolo and Kootenai National Forest landtype mapping and from NRCS soil mapping.

examples, and the Erosion analyst will need to create land type descriptions best suited to the watershed. Two publications that may be helpful are Ritter et al. (1995), which provides a good summary of geomorphic processes that shape landscapes, and Haskins et al. (1998), which describes a geomorphic classification system.

Box 2. Examples of geomorphic land types from across the United States

Alluvial fan	Kettle outwash plains
Arroyos	Landslide deposit
Alpine glaciated basin	Loess deposit
Avalanche-prone hillslopes	Marine terrace
Badlands	Mesas
Backshore terrace	Piedmont
Basin floor depressions	Plateau
Canyonlands	Playa
Chenier plain	Prairie potholes
Cliffs	Rockland
Coastal marshlands	Slough bottomlands
Dissected planar slopes	Talus
Esker	Tidal mudflats
Floodplain terrace	Till plain
Glacial moraine	Valley flat
Glacial outwash terrace	Valley headwall
Karst limestone topography	Wet meadows

A watershed can have a large range of land types depending on the scale of assessment. Since no strict criteria exist for defining land types, the scale of assessment should be determined by the objectives of the Erosion assessment. In general, a finer scale (e.g., swales > 40% slope) will be most useful for addressing specific land management activities, while a broader scale (e.g., glaciated uplands) may be more helpful for quantifying general erosion rates. Consult with other module analysts to help determine the best assessment scale. In particular, coordinate with the Channel analyst, who will be identifying channel types based on geomorphic characteristics similar to land types.

Channel ▶

Geologic maps are often useful for identifying land types at a broad scale. Soil surveys typically provide information at finer scales and can be particularly helpful in identifying land types near streams and rivers. Figure 4 shows examples of soil association patterns. The correlation of soil types and geomorphology is commonly described in soil surveys. Soil types can be used individually or in aggregate to describe a land type. Geology and soil information may also be available as GIS overlays complete with erosion potential ratings. Erosion potential or erosion hazard ratings should be examined using the available data to evaluate their accuracy and applicability to the watershed.

Land types can be further refined using modifiers such as slope gradient, slope position, slope shape, and dissection frequency or pattern (Box 3). These land type modifiers can help focus the analysis on specific areas where erosion is most problematic. In some

Figure 4a. Correlation between soil types and geomorphology in Maine

Note that the Colton soils correlate directly with the eskers land type.

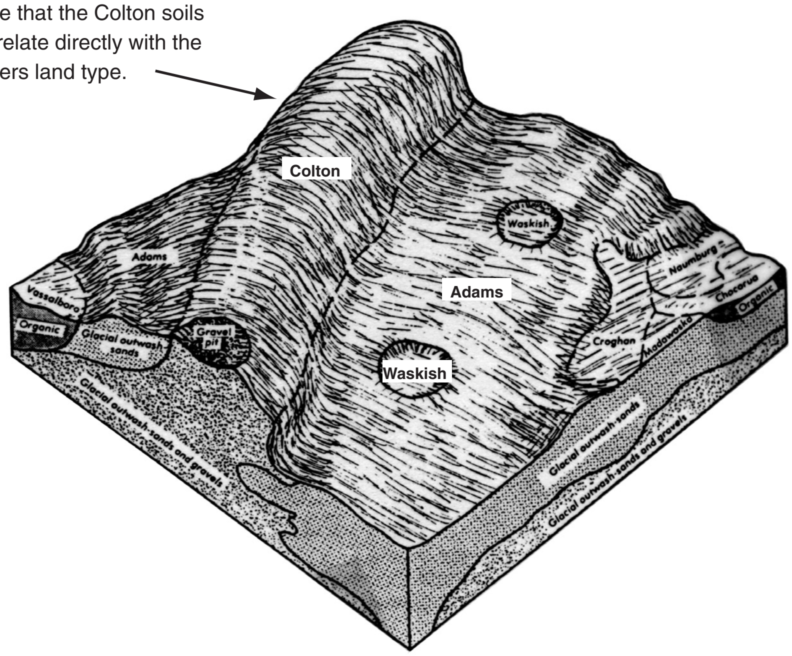
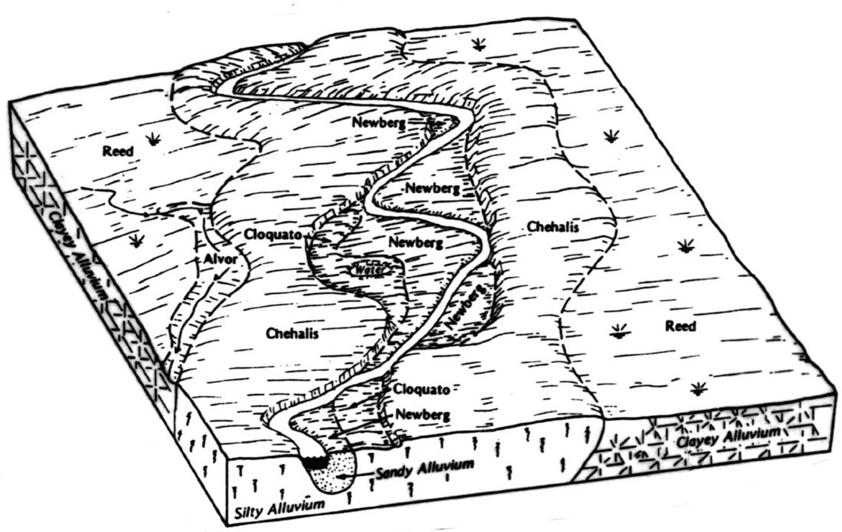


Figure 4b. Correlation between soil types and geomorphology in Washington State



Box 3. Slope class maps

Since slope gradient is often a primary factor influencing erosion potential, it may be useful to divide the watershed into similar slope classes. The increment used for slope classes will depend on the total relief of the watershed. Relatively low-relief watersheds typically will have slope class increments of 1-5 percent, while high relief watersheds may have increments of 5-20 percent. GIS programs can be used to efficiently create this type of map.

cases, it may also be useful to consider other ecological factors such as vegetation, climate, or aspect to help differentiate land types. Where possible, land types should be differentiated based on natural processes and not changes due to land use.

Step 3. Assign relative erosion potential ratings and create a refined land type map

Correlate the land types with information on erosion in the watershed. If a GIS system is available, it may be useful to overlay geology or soils maps with land use activities to highlight potential erosion concerns. It may be necessary to modify land type boundaries or develop new land types to best distinguish specific areas susceptible to erosion problems. Create a final land type map (Map E1) to use during the Synthesis process. Assign relative erosion potential ratings to each land type based on its susceptibility to mass wasting and surface erosion. It is important to remember that the erosion potential ratings in all but the most obvious cases will be hypotheses requiring additional information and further evaluation. Summarize information for each land type in Form E2.

Step 4. Produce Erosion report

The Erosion report should summarize geologic and soil characteristics, erosion processes in the watershed, and land management effects on erosion. The report will typically include the following components:

1. Site Description
   - Geology
   - Soil types
   - Topography
   - Erosion processes

2. Assessment methodology
   - Materials (e.g., aerial photo series and source)
   - Survey methods
   - Assumptions
3. Results of the assessment
   - Form E1. Summary of Erosion observations
   - Form E2. Summary of land type characteristics
   - Map E1. Land types
4. Conclusions
   - Erosion trends
   - Land management effects
   - Further data and assessment needs
   - Confidence in assessment
5. References

Level 2 Assessment

The organization of this section generally corresponds to the critical questions listed in the Erosion Module Reference Table. Most of the critical questions relate to a specific topic that can be evaluated using a number of methods or tools. For each topic, a general description of methods, guidance on the appropriate use of methods, and the expertise and time-frame required to complete the assessment are provided. Suggested references are also provided for more detail on available data, methods, and tools.

Soil Compaction

Soil compaction is typically caused by either the use of heavy machinery, such as for building construction and ground-based logging, or trampling due to animal grazing or by people, such as at heavily used recreation areas. Soil compaction may be a concern because of reduced water infiltration or reduced soil productivity for vegetation growth.

The sensitivity of soil to compaction is largely a function of soil texture. Soil texture is the relative proportion of sand, silt, and clay particles in a mass of soil. Soil with a high percentage of clay may be easily compressed. On the other hand, soil with a high percentage of sand cannot be easily compressed; thus it maintains its structure under heavy loads.

The primary method for evaluating large-scale soil compaction from urbanization, roads, and grazing is examining aerial photos. Land use maps may also provide useful information, although it may not be as accurate as information from a photo survey. To evaluate small-scale soil compaction and the degree of compaction, field surveys will be necessary. Soil compaction testers or penetrometers can be used to gather data on the compressive strength of the soil. Soil compaction from grazing or camping may only be a problem in isolated areas, such as near streams or lakes. It may also be possible to correlate field observations of compaction with specific soil types to help predict the potential for future compaction problems. Measuring and evaluating soil compaction can be easily done without extensive training, although a soil scientist may be needed for more intensive evaluations.

Landslides

Landslide evaluation on a watershed scale typically involves aerial photo analysis and creation of a landslide inventory. Typically, 1:25,000-scale or finer aerial photos are needed to accurately identify landslides. Orthophotos, if available, can be an important aid to transfer data from aerial photos to topographic maps. The landslide inventory should cover the longest period of record possible by using the oldest aerial photos through the most current photos. A long aerial photo record is important for evaluating the rate of rapid failures, such as debris flows and rockslides because of their episodic occurrence from infrequent large storms, and the movement rate of slumps and earthflows that may progress intermittently over months to centuries.

A comprehensive landslide inventory can be used to collect data that relate important variables to the risk of occurrence. A landslide inventory can include data on location (e.g., township, range, and section number), year of occurrence, type of landslide, hillslope gradient, parent material, slope form, soil type, land use trigger, or sediment delivery to a stream (Figure 5).

Figure 5. Sample landslide inventory form

Site #	Location	Year	Type	Gradient (%)	Trigger	Stream Delivery
1	21N, 15E Sec. 2	1968	Shallow rapid	70-80	Road	Yes
2	20N, 13E Sec. 31	1993	Deep-seated	30	Natural	No
3	21N, 12E Sec. 11	1951	Rockfall	60	Natural	No

Some training and experience are necessary to accurately identify landslides on aerial photos, particularly for older, inactive, or deep-seated landslides. Some field measurements may also be necessary to estimate the minimum identifiable size of landslide observable on aerial photos, landslide volumes, the frequency of smaller slides, and the frequency of slides hidden under forest canopy (Reid and Dunne 1996). Uncertainties in the aerial photo interpretation may be related to the following:

- Physical conditions that contributed to the landslide.
- Land use trigger mechanisms.
- Delivery of sediment to public resources.
- Extrapolation from areas of known hazard to areas of unknown hazard.

Further information on creating landslide inventories can be found in Sidle et al. (1985), the federal guide for watershed analysis (RIEC and IAC 1995), the Washington State watershed analysis manual (WFPB 1997), and the Oregon watershed assessment manual (Watershed Professionals Network 1999). NCASI (1985) contains data from landslide inventories in the Pacific Northwest.

Sheetwash Erosion

Sheetwash erosion is movement of soil particles caused by rainsplash and rill erosion. Sheetwash erosion occurs naturally in areas with generally sparse vegetation or after wildfire but can also be prevalent in agricultural croplands and rangelands.

Table 1 contains the results of soil loss measurements from hillside plots around North America under different land use conditions. These data can be used to derive a crude but quick estimate of erosion in a watershed. It is important to note that these soil loss estimates do not address sediment delivery to streams. Sediment delivery distances need to be estimated along with average soil loss to evaluate sheetwash erosion impacts to streams.

Revised Universal Soil Loss Equation

The most commonly used model to predict sheetwash erosion under various land uses is the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997). The publication by Renard et al. (1997) should be consulted for more detailed information and application of the RUSLE. Use of this model typically requires some expertise and familiarity with conducting erosion studies. A GIS system is also very helpful for simplifying many of the steps.

The RUSLE is best used for agricultural lands in the central and eastern United States, although refinements in values and additional data from the western United States allow its use in most agricultural areas (Renard et al. 1997). The latest version of the RUSLE (Renard et al. 1997) replaces previous versions published by the USDA.

Table 1. Measurements of soil loss from hillside plots

Land Use	Location	Soil Loss (tons/acre/yr)	Source
Forest			
Primeval	Oklahoma	0.01	Smith and Stamey (1965)
Burned annually	Oklahoma	0.11	Smith and Stamey (1965)
Primeval	North Carolina	0.002	Smith and Stamey (1965)
Burned semiannually	North Carolina	3.08	Smith and Stamey (1965)
Woodland, protected	Texas	0.05	Smith and Stamey (1965)
Woodland, burned annually	Texas	0.36	Smith and Stamey (1965)
Woodland, protected	Ohio	0.01	Smith and Stamey (1965)
Woodland, protected	North Carolina	0.08	
Agriculture, Cultivated Grasslands			
Bluegrass	Midwestern U.S.	0.02-0.34	Smith and Stamey (1965)
Alfalfa	Midwestern U.S.	0.03-0.15	Smith and Stamey (1965)
Clover and grass	Virginia	0.01-0.07	Smith and Stamey (1965)
Bermuda grass	Southwest U.S.	0.00-0.10	Smith and Stamey (1965)
Fescue grass	Georgia	0.20	
Hayland	Washington	0.01-0.08	Smith and Stamey (1965)
Hayland	North Carolina	0.31	Smith and Stamey (1965)
Tropical perennial grasses	Puerto Rico	1.2	Smith and Stamey (1965)
Tropical kudzu	Puerto Rico	0.18	Smith and Stamey (1965)
Agriculture, Croplands			
Bare fallow	Georgia	100	Barnett (1965)
Bare fallow	Midwestern U.S.	69	Bennet (1939)
Corn	Midwestern U.S.	17.86	Jamison et al. (1968)
Corn	Midwestern U.S.	73.2	Bennet (1939)
Rangeland			
Dry woodland and rangeland	Southern California	2.7	Krammes (1960)
Dry woodland and rangeland, after fire	Southern California	24.7	Krammes (1960)
Dry woodland and rangeland	New Mexico	21.2	Leopold et al. (1966)
Sparse grassland	Alberta	7.7	Campbell (1970)
Urban			
Road cuts	Georgia	79-237	Diseker and Richardson (1961)
Building sites	Maryland	125-219	Wolman and Schick (1967)
Building sites	Maryland	189	Guy (1965)
Mining			
Land devegetated by smelter fumes	Ontario	26.1	Pearce (1973)
Spoil bank	Ohio	87	Geotimes (1971, Dec)
Rural Roads			
Forest roads	Idaho	29.7	Megahan and Kidd (1972)
Forest roads	Idaho	7.9	Copeland (1965)

Adapted from Dunne and Leopold (1977)

The RUSLE is as follows:

$$A = R*K*L*S*C*P$$

Where: A = Soil loss (tons/acre)
R = Rainfall erosivity index
K = Soil erodibility factor
L = Hillslope-length factor
S = Hillslope-slope factor
C = Cropping management factor
P = Erosion control practice factor

The rainfall erosivity index (R) corresponds to the average annual energy and intensity of rainstorms and has been mapped across the United States. The soil erodibility factor (K) is the average soil loss at a specific rainfall erosivity when the soil is exposed as cultivated bare fallow. The soil erodibility factor has also been calculated for different soils across the country and is listed in most NRCS (formerly the SCS) soil surveys. The effect of topography is accounted for by the hillslope-length (L) and hillslope-slope (S) factors. Hillslope-slope factors can be estimated in the field using inclinometers or levels or in the office using topographic maps (maps with 2-foot contour intervals are recommended). Topographic factors for uniform hillslopes under various land use conditions, such as cropland, rangeland, or construction sites are listed in Renard et al. (1997). The cropping management factor (C) and the erosion control practice factor (P) account for vegetative cover and soil tillage practices, respectively. Tables with a range of factors, as well as more detailed assessments for site-specific determinations of both C and P, can be found in Renard et al. (1997).

The RUSLE is best used on smaller drainage basins by dividing the basin into areas of uniform soil type, topography, and agronomic conditions. The soil loss can then be computed for each combination. This exercise is greatly simplified if GIS can be used.

The RUSLE predicts the amount of soil moved from its original position and does not necessarily predict the amount of sediment transported out of an area or watershed. The delivery of sediment into streams or other sediment-transport conduits (e.g., gullies, ditches, canals) must be considered as a separate step. Ebisemiju (1990) found that sediment delivery was correlated with hillslope gradient and infiltration rates on bare soils but was best predicted by slope length and soil erodibility on vegetated surfaces. If redeposited sediment is observed during field work, its relation to factors such as gradient, surface roughness, vegetation cover, storm runoff, and distance from the sediment source should be noted to identify the conditions under which delivery may be significant (Reid and Dunne 1996).

Water Erosion Prediction Procedure

The Water Erosion Prediction Procedure (WEPP) is now being developed to take the place of the RUSLE (Nearing et al. 1989). WEPP is designed to be more process-based and have wider applicability to cropland, rangeland, and forestland. Independent versions are being developed for hillslopes, small watersheds, and GIS-based grid cells. Both the hillslope and small watershed versions are expected to be PC-based expert programs (Reid and Dunne 1996). Contact the NRCS for further information about the availability of WEPP.

Road Erosion

Road surface erosion is generally evaluated separately from sheetwash erosion because of its wide distribution and importance (Reid and Dunne 1996). A number of factors can affect the production of sediment from roads, including surfacing material, traffic levels, rainfall, and drainage design. Road erosion is typically of greatest concern at stream crossings, although roads parallel to streams can also cause sedimentation problems.

Watershed-scale road erosion is typically evaluated by developing an average annual rate of erosion multiplied by the area of road delivering directly to waterbodies. Erosion rates from forest roads have been calculated for a number of regions of the country. Regional examples of forest road erosion data and empirically-based road erosion models include the following:

- Appalachian forest road data (Kochenderfer and Helvey 1984, 1987; Swift 1984).
- Pacific Northwest road data (Reid and Dunne 1984; Bilby et al. 1989) and watershed analysis road erosion model (WFPB 1997).
- Interior West road data (Megahan and Kidd 1972; Burroughs and King 1989) and R1-R4 model (Reinig et al. 1991; Ketcheson et al. 1999).

The previously discussed RUSLE and WEPP models can also be adapted to estimate road surface erosion.

Gully Erosion

Gully erosion can often occur in response to roads, grazing, or agricultural impacts in fine-grained, cohesive soils. Evaluating gully erosion typically involves aerial photo and field surveys to estimate the distribution and density of gullies and to determine an average annual rate of incision.

Gully widths can often be translated into volumes by using field measurements to relate width and cross-sectional area. The SCS (1977) found that widths of active gullies are typically about 3 times their depth in cohesive soils but only 1.75 times their depth in non-cohesive soils. This report also provides equations for predicting future rates of gully head retreat based on drainage area and rainfall intensities. With any equation or predictive model, it is important to evaluate its assumptions and make sure they are applicable to the watershed being investigated. Field evidence can be used to verify retreat rates by noting when particular structures, trees, fences, and roads are affected by the gully. Cooke and Reeves (1976) used this type of field evidence to track arroyo networks in the southwestern United States.

Streambank Erosion

The rate of streambank erosion can depend on a number of factors, including flood discharge, previous precipitation, bank material, and vegetation. Bank erosion along large streams can typically be observed on sequential aerial photos. The average rate of lateral retreat together with field measurements of bank height can be used to estimate sediment production rates. Examples of studies that have examined bank erosion in different parts of the United States include the following:

- California (Lehre 1982).
- Ontario, Canada (Dickinson et al. 1989).
- Utah (La Marche 1966).

The Channel module may also gather information on streambank erosion, so it is important to coordinate activities.

Channel ▶

Other Erosion Processes–Soil Creep, Dry Ravel, and Wind Erosion

Soil creep is the slow downhill movement of the soil mantle that results from disturbance of the soil by freeze/thaw processes, wetting or drying, or plastic deformation under the soil's own weight (Dunne and Leopold 1977). Other soil displacing processes such as tree throw and biological activity are typically included in estimates of soil creep.

Measured soil creep rates typically range from 0.001 to 0.002 m per year in the United States. Saunders and Young (1983) contains a compilation of measured rates of soil creep and other surface erosion processes from around the world. Soil creep rates may be higher in areas of clay-rich soil and in areas with active earthflow movement. Local soil creep rate data may also be available from a monitoring program.

Soil creep rates are often used to estimate bank erosion of colluvial material. Colluvium is the soil and rock debris on a hillslope that has been transported from its original location. This type of bank erosion generally occurs in small streams that are tightly confined. Soil creep supplies sediment to the bank, and the rate of sediment supply to the bank is assumed to be equal to the rate of bank erosion. Further detail on assessment of soil creep is provided in the next section.

Dry ravel is most prevalent on steep, sparsely vegetated slopes. Ravel is capable of moving larger particles than sheetwash erosion, and the sediment tends to accumulate in small talus cones and sediment fans (Reid and Dunne 1996). Ravel rates are typically highest during freeze/thaw and wet/dry periods, after fires that have consumed fallen logs and other organic debris on hillslopes, or on near-vertical streambanks and roadcuts. Exposure of tree roots and accumulation of sediments can be evaluated in field surveys to estimate rates of dry ravel (Megahan et al. 1983; Reid and Dunne 1984; Reid 1989).

Since wind erosion does not supply sediment preferentially to streams, sediment production from this source is often ignored. If necessary, input rates can be estimated by assuming channel inputs are proportional to the fraction of the land surface occupied by channels and ponds (Reid and Dunne 1996).

Evaluation of Watershed-Scale Sources of Erosion

A sediment budget is a tool used to determine the relative sources of sediment from various erosion processes, natural and management-related. A complete sediment budget considers the sources and storage of sediment and the export of sediment from the watershed. While the method is generally quantitative, the estimates are considered order-of-magnitude values. Sediment budgets that focus on the sources and relative contribution of sediment to channels can be useful for comparing natural sources of sediment (soil creep, fires, natural mass wasting, etc.) with management-related sources of sediment (e.g., erosion from agriculture, forest roads, urban construction sites, grazing). The relative differences can be used to better judge the impacts of changes in land use and to help focus efforts for improved management.

These methods typically require expertise in evaluating watershed-scale erosion and experience developing sediment budgets. Reid and Dunne (1996) and Swanson (1983) provide more detailed descriptions and examples of sediment budgets. Constructing a sediment budget will require coordination with the Channel analyst to address sediment transport and storage issues.

Channel

Two approaches to estimating natural sediment production are discussed in this section: the soil creep model and the empirical sediment yield approach. The soil creep model is best used in watersheds with high topographic relief and a relatively small amount of alluvial bank cutting and when sediment yield data from the watershed or other nearby comparable watersheds are sparse. The empirical sediment yield approach relies on available data (typically from the USGS), generally collected on larger rivers, and can be used for most watershed types. If data on sediment yield are available and the soil creep model seems appropriate for the watershed, both methods should be used to get an idea of the range of error in the estimates. Both approaches are best at predicting the amount of finer sediment (sand-sized and smaller) exported from a watershed and may not capture bedload movement of larger particle sizes.

Soil creep model

The soil creep model provides an estimate of sediment yield from colluvial hillslope sources. Watershed sediment yield can be calculated using the following equation:

$$SY = C*2*L*D*SD$$

Where: SY = Sediment yield (tonnes/yr)
C = Creep rate (m/yr)
L = Length of stream (m)
D = Average soil depth (m)
SD = Average bulk density of soil (tonnes/m^3)

The creep rate is multiplied by the total stream length times 2 to account for creep on both sides of the channel. Stream lengths can be easily calculated using GIS, but the level of accuracy may need to be verified. Small streams may not be mapped and may constitute a large proportion of the stream network. Average soil depths can be estimated using soil survey information for the watershed. If soil depth varies significantly across the watershed, it may be necessary to break up the watershed into areas of uniform soil depth and then calculate erosion rates for each area. The bulk density of soil typically ranges from 1.2 to 1.7 tonnes/m^3 (SCS 1986). In the absence of watershed or regional data, an average bulk density of 1.5 tonnes/m^3 is typically used.

Empirical sediment yield approach

Channel

Where available, sediment yield data can provide accurate estimates of sediment production from watersheds. The USGS typically collects these data for watersheds around the country, but other sources may be available as well (Larsen and Sidle 1980; Dendy and Champion 1978). The sediment yield data should extend at least a few years and should especially cover times of higher streamflow, when the majority of sediment is transported. If these data are to be used as estimates of natural sediment production, the history of land use during the period of record should also be investigated. Where extensive land use practices have potentially increased erosion during the period of sediment yield data collection, the background rate can be back-calculated using information on management-related sources of sediment.

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Form E1. Summary of erosion observations

Number	Erosion Feature	Location	Observations

Form E2. Summary of land type characteristics

Land Type	Land Type Description	Total Area	Percent of Watershed Area	Mass Wasting Rating	Surface Erosion Rating	Observations